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Sedentary behavior and sleep efficiency in active community-dwelling older adults

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ABSTRACT

Objectives: Previous studies have demonstrated that aerobic exercise interventions have a positive impact on sleep efficiency in older adults. However, little work has been done on the impact of sedentary behavior (sitting, watching television, etc.) on sleep efficiency.
Methods: 54 Community-dwelling men and women >65 years of age living in Whistler, British Columbia (mean 71.5 years) were enrolled in this cross-sectional observational study. Measures of sleep efficiency as well as average waking sedentary (ST), light (LT), and moderate (MT) activity were recorded with Sensewear accelerometers worn continuously for 7 days.
Results: From the univariate regression analysis, there was no association between sleep efficiency and the predictors LT and MT. There was a small negative association between ST and sleep efficiency that remained significant in our multivariate regression model containing alcohol consumption, age and gender as covariates. (standardized β correlation coefficient -0.322, $p=0.019$). Although significant, this effect was small (an increase in sedentary time of 3 hours per day was associated with an approximately 5% reduction in sleep efficiency).
Conclusions: This study found a small significant association between the time spent sedentary and sleep efficiency, despite high levels of activity in this older adult group.

1. Introduction

Only approximately 5% of North Americans meet current guidelines for physical activity, due to high levels of sedentary behavior (such as sitting, or watching television) [1]. This high level of inactivity is one possible etiology for difficulty sleeping, a problem which afflicts large numbers of North Americans [2,3]. Advancing age is characterized by increasing levels of sedentary time [4] and increasing impairments in sleep duration and sleep quality [5]. Poor sleeping is recognized as a "nontraditional" cardiovascular risk factor and is associated with increased cardiovascular risk, increased rates of diabetes, and increased rates of obesity [3].

Much work has been done previously in community-dwelling older adults on the relationship between the level of physical activity and sleeping. These studies have involved direct comparisons between physically fit and unfit groups [6,7], cross-sectional observational studies [8–11], and randomized controlled trials of aerobic training [12–15]. The endpoints used in these investigations have included sleep quality scales [6,8,9,13,16], accelerometer-based measures of sleep efficiency [17] and the number of awakenings during

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sleep lab studies [7,12,14]. The time spent in sedentary behaviors is being increasingly recognized as an independent cardiometabolic risk factor (even after accounting for times spent being physically active [18]). Whether the amount of time spent sedentary is an independent predictor of poor sleep efficiency in older adults remains unexamined.

In order to more fully isolate the effects of sedentary time on sleep efficiency, we chose to recruit a group of older adults that were extremely physically active. By examining a group that was already meeting or exceeding current guidelines for physical activity, we sought to examine the relationship between sedentary behaviors (as quantified by accelerometer measures) and sleep efficiency in an active older adult population. We hypothesized that increased sedentary time would continue to be associated with poor sleep even in the setting of concomitant high levels of exercise.

2. Methods

This was a cross-sectional observational study. This study was approved by the Human Subjects Committee of the University of British Columbia, and all subjects gave written informed consent.

2.1. *Subjects and recruitment*

55 community dwelling men and women >65 years of age were screened through their affiliation with the Whistler Seniors Ski Team of British Columbia, Canada, via a study poster and information session. Subjects were enrolled between October of 2011 and June of 2012.

2.2. *Inclusion/exclusion criteria*

All subjects had to be able to independently perform all basic activities of daily living, climb one flight of stairs and walk 2 blocks without assistance. Current smokers, users of recreational drugs, those with known diabetes mellitus or cardiovascular disease in the form of prior strokes, transient ischemic attacks, angina, myocardial infarction or coronary revascularization in the last 2 years were non-eligible.

2.3. *Research procedures*

A minimum of one study visit was required by each participant to collect anthropomorphic, blood pressure, laboratory and clinical data, and to apply the accelerometer. Anthropomorphic measurements were recorded including height without shoes measured by stadiometer to the nearest 0.1 cm. Weight was measured by mechanical beam balance scale to the nearest 0.1 kg while the subject was wearing light clothes but no shoes. Waist circumference was measured to the nearest 0.1 cm by a plastic tape measure held at the level of the umbilicus directly against the skin. Blood pressure was measured by digital sphygmomanometer while the subject was seated quietly, recording the average of 3 readings taken 5 min apart, after 20 min of quiet rest. Blood was drawn in private affiliated laboratories according to standard methods.

Each subject on entry to the study was screened by a research nurse, who took a nursing history including past medical history, medication list and substance use.

Sensewear Pro armband triaxial accelerometers (BodyMedia, Sword Medical Limited, Blanchardstown, Dublin) were fitted snuggly around the right upper triceps and used to monitor levels of physical activity 24 h a day for 7 full days. Subjects were instructed to wear it continuously, including during sleep, except when bathing or swimming. The Sensewear Pro measures triaxial acceleration, skin temperature, galvanic skin response, and heat flux from the body, which is then processed by algorithms to calculate and report physical activity and sleep duration. Minute-by-minute epoch data from the Sensewear Pro was analyzed by algorithms using Body Media InnerView Research Software (Version 5.1, BodyMedia, Inc.).

2.4. *Data collection and processing*

To be included in the analysis, participants were required to comply with wearing the accelerometer for at least 5 valid days. A valid day was defined as at least 21 h of recorded activity on the accelerometer.

2.5. *Accelerometer measures of activity*

Accelerometer data was recorded in one second epochs. Sedentary behavior was defined as "any waking behavior characterized by an energy expenditure ≤ 1.5 METs while in a sitting or reclining posture" [19]. Light activity, meaning time spent standing or walking slowly, was categorized as 1.5–3.0 METs. Moderate to vigorous activity such as brisk walking or more intense exercise was categorized as >3.0 METs. Subjects qualified as meeting target guidelines for physical activity when more than 150 min in the 7 days was spent at a moderate to vigorous level of activity. Average time per day spent in sedentary (ST), light (LT) and moderate to vigorous activity levels (MT) was recorded as minutes per day. Based on a systematic review of accelerometry practice for older adults [20], the following cut points were used: ≤ 99 counts/min as sedentary time, 100–1951 counts/min as light physical activity, and ≥ 1952 counts/min for moderate to vigorous level of activity [21].

2.6. *Accelerometer measures of sleep efficiency*

Accelerometers were also worn during the night to provide a measure of sleep efficiency, which is defined as the number of minutes of sleep divided by the number of minutes in bed. The Sensewear Pro can distinguish between lying down and sleep time by using algorithms that detect the characteristic combination of orientation, motion, temperature, and skin conductivity with each state (Body Media InnerView Research Software, Version 5.1). The activity monitor has been validated to examine sleep efficiency against polysomnography [22,23] in adult subjects and has been used previously to evaluate sleep efficiency in older subjects [24,25].

2.7. Statistical analysis

All measures of physical activity were normalized by the amount of time per day the accelerometer device was worn. Our primary response variable was sleep efficiency (number of minutes of sleep divided by the number of minutes in bed as a percentage). In addition to our measures of physical activity (ST, LT and MT), variables to be considered as predictors in the multivariate linear regression model were determined a priori. These predictors consisted of age, gender, weekly alcohol consumption, weekly caffeine consumption and the use of sedatives.

Scatterplots were visually inspected for outlier data and density plots were examined to identify data skewing. Any predictors that demonstrated skewing were logarithmically transformed (base 10) prior to both the univariate and multivariate analyses. A tiered approach was used for the analysis whereby the initial model contained all of our predictor variables. A stepwise method was used to generate each successive regression model, with criteria for removal of variables being the least significant predictor with a p-value of greater than 0.10. With each iteration of the stepwise regression model the least significant predictor was removed. Akaike's Information Criterion (AIC) was calculated after each predictor was removed from the model, until the smallest AIC was obtained [26]. To ensure the assumptions of the multivariate regression were met, tolerance values and variance inflation factors were examined for multi-colinearity. In order to avoid colinearity any variables that demonstrated significant correlations in the univariate regression analysis were not placed in the initial model. Plots of residuals and a QQ plot were examined in our final minimum effective model. The R core software package version 3.0.1 was used for statistical analysis with a significance level of $p<0.05$ [27].

3. Results

55 Individuals were screened and 1 individual met our exclusion criteria (cardiovascular event in the last 2 years). Of the 54 originally recruited, there was 1 withdrawal, 1 case where the participant did not meet the accelerometer compliance criteria, and 1 case of where the monitor was worn incorrectly. This left a total of 51 subjects (24 men, 27 women) who contributed to the data analysis. The accelerometers were worn for an average of $98.5 \pm 0.2\%$ of the study time. Data was otherwise complete (Fig. 1).

3.1. Participant characteristics

Demographic and metabolic characteristics of participants are shown in Table 1.

3.2. Activity levels

On average, subjects spent 156 min (2.6 h) per day performing moderate to vigorous physical activity, 236 min (3.9 h) per day in light activity, and 1046 min (17.4 h) of their time sedentary. 562 mins (9.4 h) of sedentary time was accumulated apart of time spent lying down (Table 1). All but 1 subject met the target of 150 min per week of moderate to vigorous physical activity recommended in the American College of Sports Medicine guidelines [28].

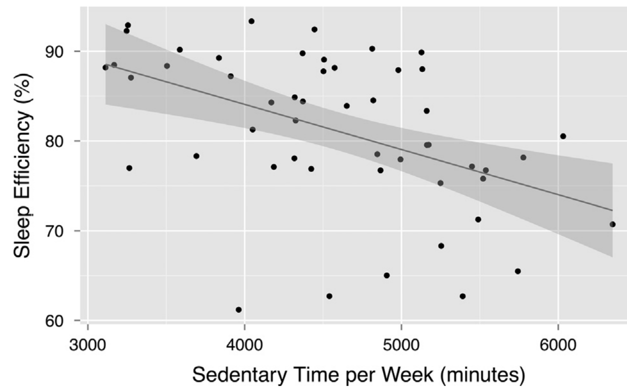

Fig. 1 – Correlation between sedentary time (minutes/week) and sleep efficiency (percent): graph demonstrating the small negative correlation between amount of time spent sedentary (minutes per week) and sleep efficiency. Sedentary time was normalized for monitor wear time.

3.3. Activity, sleep and demographic correlates (Tables 2 and 3)

MT, caffeine intake and alcohol intake all demonstrated skewing on inspection of the density plots and were therefore logarithmically transformed (base 10) prior to the analysis. In the univariate regression analysis, ST was the only activity parameter that showed a significant correlation with sleep efficiency (Table 2).

The predictors ST, age, alcohol intake, gender and caffeine intake were entered into a multivariate regression model that initially explained 48% of the variance in sleep efficiency (Model 1). MT and LT were not placed into the model due to the fact they showed no correlation with sleep efficiency in the univariate regression analysis. Sedative use also could not be entered into the initial model since none of the recruited subjects took sedating agents. None of these predictors showed a significant ($p<0.05$) correlation with each other, so there were no issues with multi-colinearity.

Our best fit model (Model 3, as determined by AIC) explained 47% of the variance in sleep efficiency and consisted of

$$\text{Sleep efficiency} = b_0 + b_1(\text{ST}) + b_2(\text{age}) + b_3 \log(\text{caffeine intake}) + e$$

where b_0 is an intercept term, b_1 represents the change in sleep efficiency with an increase in ST, b_2 is the change in sleep efficiency with an increase in age, and b_3 is the change in sleep efficiency with an increase in the logarithm (base 10) of caffeine intake (with all other predictors held constant). The error term e represents all sources of unmeasured and unmodeled random variation in sleep efficiency (Table 3). Although statistically significant, the effects of increasing sedentary time were small (a decrease in sleep efficiency of 5% for every 3 h increase in ST per day with age and caffeine consumption held constant).

Table 1 – Demographic, metabolic and activity characteristics ($N=51$) The demographic, cardiometabolic risk factors and activity level of study subjects are shown. Heavy drinking was defined as greater than 7 drinks per week in women and greater than 14 drinks per week for men. BMI, body mass index; LDL, low-density lipoprotein; HDL, high-density lipoprotein; and MET, metabolic equivalent of task.

Age (years), range	71.5 ± 0.6	(65–81)
Gender (female)	27	(54%)
Demographic variables		
Caucasian	46	(92%)
Moderate–heavy alcohol	16	(32%)
Ex-smokers	25	(50%)
University/further education	44	(88%)
Peak income >$60,000	35	(70%)
Metabolic variables		
Waist circumference males (cm)	92.9 ± 1.9	
Elevated waist circumference	4	(8%)
Waist circumference females (cm)	81.9 ± 1.6	
Elevated waist circumference	7	(14%)
BMI (kg/m^2)	24.2 ± 0.4	(16.5–32.4)
BMI ≤ 18.5	1	(2%)
BMI 18.51–24.9	32	(63%)
BMI 25–29.9	19	(37%)
BMI ≥ 30.0	2	(4%)
Triglycerides (mmol/l)	1.01 ± 0.08	(0.3–3.61)
LDL cholesterol (mmol/l)	2.86 ± 0.01	(1.25–4.66)
HDL cholesterol (mmol/l)	1.85 ± 0.07	(0.85–3.28)
Systolic blood pressure (mmHg)	117 ± 2	(90–166)
Systolic ≥ 140	7	(14%)
Diastolic blood pressure (mmHg)	68 ± 1	(55–93)
Diastolic ≥ 90	2	(4%)
Fasting plasma glucose (mmol/l)	5.11 ± 0.10	(3.4–9.1)
Pre-existing medical conditions		
Anti-hypertensive medication	13	(26%)
Lipid lowering medication	5	(10%)
Average time per day at activity levels (min)		
Lying down	483.9 ± 7.8 (341.6–604.2)	(33.6%)
Sedentary (<1.5 METs)	1046.0 ± 13.1 (829.8–1269.6)	(72.6%)
Light (1.5–3.0 METs)	235.8 ± 10.0 (91.1–431.2)	(16.4%)
Moderate–vigorous (>3.0 METs)	155.9 ± 11.4 (14.9–417.5)	(10.8%)
Sleep duration	394.4 ± 9.8 (252.0–535.4)	(27.4%)

4. Discussion

Our study demonstrated that in a highly active older adult population, waking time spent in sedentary behavior has a significant, but clinically quite small negative association with sleep efficiency. The seniors in our study were unique in their high levels of activity, spending an average of 2.6 h each day engaging in moderate to vigorous activity. This level of activity exceeded the 2.5 h per week recommended by the American College of Sports Medicine guidelines [28]. Although the study population exercised more than the American average [29], ST was congruent with the average ST for the general older adult population (9.4 h per day) [21]. Despite the high level of sedentary behavior noted in our study population, our findings suggest that high levels of physical activity can blunt the impact of ST on sleep efficiency, suggesting that inteventions to reduce ST would have limited effects on sleep efficiency.

The relationship between physical activity and improved sleeping has been well established in community-dwelling older adults. Direct comparisons between physically fit older adults and sedentary older adults have demonstrated better sleep efficiency during formal sleep studies [7] and higher ratings of sleep quality on a visual analog scale [6] in physically fit seniors. Similarly, cross-sectional studies of larger groups of older adults have demonstrated a significant positive correlation between scores on physical activity scales and scores on sleep quality scales [8,9]. Other investigations that used accelerometer-based measures of activity in community-dwelling older adults have demonstrated a small positive relationship between sleep efficiency and daily energy expenditure [11] and sleep efficiency and daily activity counts [10], although none looked at sedentary time as an independent factor. Randomized controlled trials (RCT) of aerobic exercise in sedentary older adults with sleep complaints have been shown to reduce the number of awakenings during sleep studies [12,14], and improve sleep efficiency as measured by accelerometer [15]. In addition, a RCT of aerobic training in older adult caregivers demonstrated improvements in the Pittsburgh Sleep Quality Index (PSQI) after 12 months [13].

Our study did not demonstrate any significant relationship between LT or MT and sleep efficiency, contrary to the results of other investigators. This is understandable in the context of our study population; we intentionally examined highly active subjects in order to better isolate the impact of sedentary time on sleep. Our study population did not have enough of a variation in LT and MT to adequately examine the impact of these behaviors on sleep efficiency.

4.1. Possible mechanisms

Although a definitive examination of the reasons behind the negative relationship between ST and sleep efficiency is beyond the scope of the current study, several mechanisms might be hypothesized. Physical acitivity has been shown to improve obstructive sleep apnea [30], depressed mood [12] and restless leg syndrome [31], all conditions common in older adults that affect sleep efficiency. Exposure to sunlight has also been a hypothesized factor relating activity and improved sleep [8]. A study of nurses has shown a strong negative association between ST and melatonin levels [32], making this another potential mechanism. Another possibility is that poor sleep results in greater amounts of ST due to subject fatigue during waking hours [33,34]. However, given that our subjects exercised for an average of 2.6 h per day, physical fatigue seems an unlikely explanation in our population. Overall, the relationship between ST and sleep efficiency was quite clinically small in our

Table 2 – Univariate regression analysis ($n=51$). The Pearson correlation coefficients for the predictor variables (ST, LT, MT, age, alcohol consumption, and caffeine consumption) with the response variable (sleep efficiency) are shown, along with 95% confidence intervals and the p-values. ST, sedentary time; LT, light activity time; MT, moderate activity time; R, Pearson correlation coefficient; and CI, 95% confidence interval.

Response variable	Predictors	R (CI 95%)	p Value
Sleep efficiency	ST	−0.472 (−0.662 to −0.226)	<0.001
	LT	0.005 (−0.271 to 0.281)	0.970
	MT	−0.125 (−0.387 to 0.156)	0.383
	Age	0.058 (−0.221 to 0.328)	0.688
	Alcohol consumption	0.108 (−0.173 to 0.372)	0.452
	Caffeine	−0.117 (−0.425 to 0.215)	0.489

Table 3 – Stepwise multivariate regression analysis ($n=51$). Stepwise multivariate regression models of sleep efficiency (percent) with sedentary time (ST, minutes per day), age (years), alcohol consumption (drinks per week), gender, and caffeine consumption (cups per day). The model with the best fit was Model 3 (lowest AIC, Akaike's Information Criterion) containing ST, age and caffeine consumption. Both alcohol consumption and caffeine consumption were logarithmically transformed (base 10). The units of the unstandardized coefficients (β) for ST are in % x min per day. The β for caffeine consumption is in % x cups per week. Standard errors (SE) and tests of significance are at a level of $^*p<0.05$. R^2, coefficient of determination; ST, sedentary time; LT, light activity time; MT, moderate activity time; SE, standard error, and β, beta-coefficient.

Sleep efficiency (%)	R^2	Unstandard-ized β (SE)	Standardized β	p value
Model 1:	0.478			<0.001*
$F(5,45)=5.67$				
AIC=257.0				
ST		−0.00736 (0.00144)	−0.691 (0.135)	<0.001*
Age		0.562 (0.279)	0.293 (0.145)	0.053
Alcohol consumption		0.584 (1.324)	0.0649 (0.147)	0.662
Gender		−1.34 (2.47)	−0.158 (0.290)	0.590
Caffeine consumption		−4.08 (2.07)	−0.304 (0.155)	0.058
Model 2:	0.474			<0.001*
$F(4,46)=7.22$				
AIC=255.2				
ST		0.00736 (0.00142)	−0.691 (0.133)	<0.001*
Age		0.568 (0.276)	0.296 (0.143)	0.047*
Gender		−1.15 (2.40)	−0.135 (0.282)	0.635
Caffeine consumption		−3.76 (1.92)	−0.280 (0.143)	0.059
Model 3:	0.471			<0.001*
$F(3,47)=9.78$				
AIC=253.5				
ST		−0.00741 (0.00140)	−0.695 (0.132)	<0.001
Age		0.541 (0.267)	0.282 (0.139)	0.051
Caffeine consumption		−3.894 (1.877)	−0.290 (0.140)	0.046*

study, suggesting that high levels of physical activity blunts the effects of sedentary behavior.

4.2. Clinical implications

Both poor sleep and sedentary activities co-exist quite commonly in older adult populations and have profound impacts on both health and quality of life [4,8]. ST has previously been shown to have an impact on cardiovascular risk factors such as waist circumference and insulin sensitivity that are completely independent of the amount of time spent being physically active [18]. The results of our investigation suggest that unlike cardiovascular risk factors, a reduction in ST would not result in large improvements in sleep efficiency in older adults that are already highly physically active.

4.3. Study limitations

There are some potential limitations to our study findings. The cross-sectional nature of the study design limits inference about causality. Ideally prospective or preferably interventional trials are needed to define the specific physiologic and behavioral factors behind the associations observed. In addition, the highly active nature of our study population makes generalizability of our results to less active populations problematic. In addition, accelerometer-based measures are not as accurate at measuring sleep quality as formal sleep lab-based studies.

5. Conclusions

This study found a cross sectional relationship between ST and sleep efficiency, despite high levels of activity in this older adult group. The size of this relationship however was quite small, suggesting a reduction in ST would not result in large improvements in sleep quality in older adults that already have the protective effects of high levels of physical activity.

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